EXPERIMENTAL EVALUATION OF NEW PIPE SLEEVE WITH WEEP HOLES FOR CONCRETE LEAKAGE PREVENTION

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I dedicated this thesis to my beloved family. Special thanks to my mother, Mrs. Azizah Mohamed, who always give me endless hope, support and prayer to complete my master degree. My siblings who have always give me encouragement, strength and love. Thank you for always be with me. May Allah bless all of you more than enough.

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ABSTRACT

Mortar is a layer with high water absorption rate over concrete due to its porous structure. The mortar layer that frequently exposed to water or moisture is more likely to contain moisture in its layer. The example of area that is mostly exposed to water is the bathroom. The water infiltrated and trapped in the mortar slab in the bathroom will eventually increase the moisture content of the mortar slab and will raise many problems such as the deterioration of the building structure surface. Therefore, this study has been carried out to produce a technology to remove the trapped water in the mortar slab and to reduce the moisture content in the mortar layer. The infiltration rate of the water into the mortar slabs installed with the conventional pipe sleeve (T1), the circular weep-holes pipe sleeve (T2), the vertical weep-holes pipe sleeve (T3) and the inclined weep-holes pipe sleeve (T4) have been measured and the results show that T4 has recorded the highest reading of 7.74 ml/min compared to other pipe sleeves. Besides that, T4 has also recorded the highest water flow rate out of the mortar with 1.31 ml/min and recorded the lowest moisture content of 10.1%. Inclined weep-holes pipe sleeve was proven able to work better than other designs. Therefore, the New Pipe Sleeve (NPS) performance with inclined weep-holes designs are studied in depth by changing the weep-holes angles to 15°, 30°, 45°, 60° and 75° and weep-holes surface area of 6%, 8% and 10%. As a result, the weep-holes angle of 60° with 10% weep-holes surface area has recorded the highest water infiltration rate and water flow rate out of the mortar with 20.898 ml/min and 3.764 ml/min, respectively, obtaining the highest reduction of the moisture content by 3.1%. The optimum performance of the pipe sleeve with inclined weep-holes design has been proposed by using Design Expert Software and the optimum performance can be achieved with the used of the weep-holes angle of 69.55° and 10% weep-holes surface area, producing water infiltration rate of 20.4513 ml/min and water flow rate out of the mortar of 3.3795 ml/min. Therefore, application of optimise design of weep-holes has promising potential method to reduce leakage and fungi problem that normally occurred in bathroom area.

ABSTRAK

Mortar adalah suatu lapisan yang mempunyai kadar serapan air yang tinggi berbanding konkrit disebabkan strukturnya yang berliang. Lapisan mortar yang terdedah dengan kerap kepada air atau lembapan berisiko tinggi untuk memerangkap lembapan di dalam lapisannya. Contoh kawasan yang paling kerap terdedah dengan air adalah bilik mandi. Air yang terperangkap di dalam lapisan lantai bilik mandi lama-kelamaan akan meningkatkan kadar kelembapan mortar dan akan menyebabkan berbagai masalah seperti kemerosotan permukaan struktur bangunan. Oleh itu, kajian ini telah dijalankan untuk menghasilkan suatu teknologi bagi mengeluarkan air yang terperangkap di dalam lapisan mortar. Kadar serapan air ke dalam lapisan mortar yang dipasang dengan *pipe sleeve* biasa (T1), *circular weep-holes* (T2), *vertical weep-holes* (T3) dan *inclined weep-holes* (T4) telah disukat dan hasilnya menunjukkan bahawa T4 telah mencatatkan bacaan tertinggi iaitu sebanyak 7.74 ml/min berbanding *pipe sleeve* lain. Selain itu, T4 juga telah mencatatkan kadar pengeluaran air tertinggi daripada lapisan mortar iaitu dengan 1.31 ml/min serta mencatatkan bacaan kandungan lembapan terendah iaitu 10.1%. *Inclined weep-holes* terbukti berfungsi dengan lebih berkesan berbanding *pipe sleeve* lain. Oleh itu, prestasi *New Pipe Sleeve (NPS)* dengan *inclined weep-holes* dikaji dengan lebih mendalam dengan mengubah sudut *weep-holes* kepada 15°, 30°, 45°, 60° dan 75° serta menggunakan variasi luas permukaan *weep-holes* sebanyak 6%, 8% dan 10%. Hasilnya, *weep-holes* bersudut 60° dengan 10% luas permukaan mencatatkan bacaan kadar serapan air dan pengeluaran air tertinggi berbanding rekabentuk lain iaitu dengan 20.898 ml/min dan 3.764 ml/min serta mencatatkan pengurangan kadar lembapan tertinggi sebanyak 3.1%. Prestasi optimum *inclined weep-holes* telah dicadangkan oleh *Design Expert Software* dan mampu dicapai dengan menggunakan *weep-holes* bersudut 69.55° serta 10% luas permukaan *weep-holes* bagi memperolehi 20.4513 ml/min kadar serapan dan 3.3795 ml/min kadar pengeluaran air. Oleh itu, rekabentuk optimum *weep-holes* pada *pipe sleeve* mampu mengurangkan masalah lantai bocor dan kulat yang kebiasaannya berlaku di kawasan bilik mandi.

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LIST OF SYMBOLS AND ABBREVIATIONS

mm	Millimeters
ml	Milliliters
min	Minute
r	Radius
d	Diameter
b	Weep-holes base length
h	Height
π	Pie (3.142)
A	Area
b	Weep-holes base length
h	Height
3D	Three dimensions
NPS	New Pipe Sleeve
uPVC	un-Plasticized Polyvinyl Chloride
OPC	Ordinary Portland Cement
BS	British Standard

CHAPTER 1

INTRODUCTION

1.1 Background of study

A building is a structure built with a variety of purposes, for example, as a shelter for human protecting them from extreme weather. Buildings nowadays are mainly constructed by using concrete. This is because concrete buildings have better strength compared to other buildings material. Besides, the concrete is equipped with fire and wind resistance properties. Their construction process is also rapid and economic.

The concrete slab is one of the main structural members of a concrete building having a flat horizontal structure made of concrete containing reinforcement called reinforced concrete. The function of the slab is as a building level separator.

A layer of slab consists of concrete, mortar, and tiles layer. However, especially in the bathroom area, there is a waterproof layer applied in between the mortar and the concrete layer. The waterproof coating is a layer functioning as a water resistance layer to prevent the water inside the mortar to penetrate into the concrete layer that contains reinforcement steel. However, the waterproof layer will be functioning effectively normally between five to ten years, depending on the quality of slab waterproofing installation work (Tsukagoshi et al., 2012).

Leakage is an accidental admission or escape of liquid or gas, through a hole or crack. In other words, leakage is the gradual escape of an electric charge, current, or magnetic flux. The leakage of water in a concrete slab is due to many reasons. One of them is because of the porosity of the concrete. The initial porosity of the concrete is determined by the sum of the mixing water volume, intentionally entrained air, and accidental voids due to the incomplete compaction. Therefore, the porosity of the mortar can leads to leakage problem (Dry, 2000; Lu & Zhou, 2000; Konečný & Lehner, 2016).

Porous is a permeable to water, air, or other fluids. Porosity is the fraction of the volume that is not occupied by particles or solid material, and therefore can be expressed as total porosity or interparticle porosity. Since aggregates contain some porosity, water can be absorbed into the body of the particles or retained on the surface of the particle as a film of moisture (Van Belleghem et al., 2016).

In a building, one of the most commonly and widely used facility is the bathroom. Since bathrooms are usually a wet area, any flaws during construction of a bathroom can be seen below the dwelling unit after completion. Bathroom leakages are common occurrences and such problems are always challenging for most building maintenance personnel to resolve.

This research generally aims to study the behaviour of mortar installed with pipe sleeve. Furthermore, this study has proposed a new system in order to reduce the possibility of slab leakage and to increase the lifespan of waterproofing layer.

1.2 Problem statement

Water is an element that can exist in three states, which are liquid, solid, and gas. Water, in the form of liquid and gas, can flow and penetrates the structure with pores or crack, allowing its movement in the structure. The concrete or the mortar surface definitely consists of small pores allowing water penetration in the structure. This water penetration will result in leakage problem in a building.

The water leakage is a key factor deteriorating the concrete and the mortar structures since it can aggravate the chemical corrosion and frost damage (Ohama, 1996; Iftimie et al., 1998; Turkmen, 2003; Song et al., 2009). The problem occurred when the water is able to penetrate into the concrete layer through seepage, due to the presence of a crack or due to the high porosity of the concrete or the mortar. Normally, leakage was found mostly in the bathroom area, especially at the upper level. Even though a water resistant and a waterproof coating has been applied to the slab surface during the slab finishing process, some portion of water will penetrate into the mortar layer via tiny pores due to the porosity of the mortar itself or the existence of a crack. The hydraulic penetration process (in the form of moisture) could be categorised using three fundamental mechanisms, which are absorption, condensation, and capillarity (Freitas & Abrantes, 1996).

No matter how good the technology has been invented to prevent water penetration, the water will inevitably flow through any void area in the concrete (Jafarifar et al., 2014; Benavente et al., 2015). Without a proper treatment and immediate action, floor or slab leakage will cause a serious problem to the building in the future, such as corrosion of steel reinforcement, fungus attack on the wall surface, formation of stalactites from the concrete slab, and disturbing the electrical wiring system (Islam et al., 2014). As a result, the cost of maintenance will increase due to the needs of a major repair to the affected building (Tsukagoshi et al., 2012).

In order to reduce the maintenance cost, the precautions should be taken by using the technology or system to prevent the problem occurring in the future. Based on previous findings, new technology or innovation is needed to enhance the existing product and technology. Preventing the water penetration into a deep layer of the concrete is not enough to prevent the concrete slab leakage, since the behaviour of the water that kept searching for the occurrence of seepage and flows through it. Thus, a suitable design of innovative tool or system that could properly remove the trap water in the concrete or the mortar has high potential to be a part of the solution for floor leakage prevention. Therefore, this study was conducted to investigate the hydraulic behaviour of the mortar as a fundamental knowledge to design an effective system that could remove water from the slab layer.

1.3 Objectives

The objectives of this study are:

i. To study the hydraulic characteristic of mortar slab based on the infiltration and the moisture rates at a laboratory scale testing
ii. To investigate the hydraulic performance of New Pipe Sleeve based on the flow rate and the moisture in the tested mortar layer
iii. To propose the optimal design of New Pipe Sleeve based on the output response of hydraulic factor in mortar using the response surface method

1.4 Scope of study

The main intention of performing this study is to develop a new design of pipe sleeve that able to drain out the liquid and moisture from the mortar system in a bathroom. Mortar slabs with the dimension of 300 mm (length) x 300 mm (width) and 50 mm height that installed with conventional and variety of new pipe sleeve designs were cast for testing purposes. The new designs of pipe sleeve have considered the weep-holes angles of 15º, 30º, 45º, 60º and 75º and the weep-holes surface area of 6%, 8%, and 10% which are in contact with the mortar layer. Laboratory test such as the infiltration test, the flow rate test and the moisture test was conducted to obtain the data needed to investigate the hydraulic performance of the mortar while using the new design of pipe sleeve. The data obtained was then analysed by using Design Expert Software to determine the optimal design of pipe sleeve.

1.5 Significance of study

The study of the floor leakage is significant to the industries, especially in the construction industry. One of the benefits of this study is the invention of a new floor leakage preventive technology. This technology successfully minimises the moisture content in the mortar layer and indirectly will minimise the risk of floor leakage from occurring. Although the layer of concrete was applied with waterproof coating, the new technology invented can protect the layer of mortar from bearing a large amount of water in its layer. The water inside the mortar layer flows out through the weep-holes design functioning as the water removal system compared to the ordinary pipe sleeve which does not have weep-holes at their surface. This absolutely will increase the lifespan of the waterproof layer and indirectly reduce any slab and wall maintenance cost.

Moreover, this study has also produced useful data such as the water infiltration rate in the mortar and the flow rate of water out of the mortar installed with New Pipe Sleeve (NPS). These data definitely benefit other researchers, who will conduct a study related to this topic, where it can be used as a guideline or reference. Consequently, it will help them to produce better findings and can improve the industries especially the construction industry.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The literature review was made based on the reading and the understanding process of books, notes, journal and all articles related to the study. In this chapter, explanation of theories and processes related to the concrete, the mortar and the leakage problem were explained in details.

Concrete and mortar are parts of building structure including slab. Concrete slab is a layer containing steel reinforcement bars, to strengthens the slab from any failure due to load supported by the slab. Meanwhile, mortar layer is a layer of a mixture of cement and sands that covered the concrete top surface. Both concrete and mortar are important component not only to form a durable building structure but also reflecting the aesthetic value of a building. However, this two layer of structure are exposed to many issues that might degrade their performance and structure surface.

2.2 Recent issues of concrete structure problem

The concrete and the mortar are an important structure in the construction industry. The statistic of the concrete usage and the concrete production shows that concrete is often chosen compared to steel. This is due to its low cost and simple production process of concrete compared to steel that is more expensive. According to Aprianti (2015), other important properties of a concrete beside its strength are including easily moulded into any forms, an engineered material that can meet almost any desired specification, adaptable, quite incombustible, affordable, and easily obtained.

Concrete has an excellent mechanical and physical characteristic if properly designed and manufactured. However, despite the advantages of concrete, there are also problems occurred related to concrete as described next.

2.2.1 Structure durability

The problem with the durability of the concrete structure usually starts with the materials deterioration. Even though at the beginning, the materials deterioration does not cause any immediate safety problems, it gradually creates a potential danger for the whole structure (Pan et al., 2017). Many studies have been conducted over the last 40 years due to the economic impact caused by the concrete durability problem. Several methods have been proposed to provide a better-reinforced concrete structure or durable concrete. The most common strategy applied is by delaying the process of reinforced concrete degradation. One of the way to delay the degradation process is by reducing the porosity of concrete by lowering the water/cement ratio. However, this kind of method has two weaknesses. First, the protection might be sufficient in highly aggressive environments, such as alkaline land, marine frigid, and saline area. Second, this method can generally lead to the overdesigning of the whole structure (Pacheco-Torgal & Jalali, 2009; Pigino et al., 2012; Franzoni et al., 2014; Pour-Ali et al., 2015).

Therefore, several approaches, which are more economical, are applied to provide an additional protection to the concrete and the mortar materials against deterioration and degradation. For example, concrete surface treatment, metal, epoxy resin and polymer coatings for steel rebar, corrosion inhibitor, and electrochemical method. Among these methods, metal, epoxy resin, polymer coating for steel bar and corrosion inhibitor are not suitable to be used in the old structure and the effects of coatings to the reinforced steel will cause a controversial issue since the corrosion rate increases rapidly in the broken areas of the coatings. By far, the effect of corrosion inhibitors to prolong the service life of a steel bar is still unclear. Meanwhile, the electrochemical method can be used in the existing structures but with a relatively expensive cost. On the other hand, the concrete surface treatment has received wider acceptance due to its effectiveness in preventing the ingress of aggressive substances.

2.2.2 Concrete fatigue

A material is said to fail in fatigue if a failure occurred after a number of repeated loads. This behaviour existed only when the maximum compressive stress of the concrete in any load cycle remains below the limiting value known as fatigue limit or endurance limit, without the occurrence of tensile during any loading or unloading (Raina, 1999).

Naik et al. (1993) stated that the concrete fatigue behaviour is influenced by several factors such as loading, the range of loading, rest period, material properties, and environmental conditions. On the contrary, the properties of concrete are depended on moisture content, water-cement ratio, cement content, air content, curing technique, age, and admixture content. Concrete fatigue refers to the phenomenon of rupture under repeated loadings, which is smaller than a single static load that exceeds the strength of the material. Fatigue is exhibited when a material fails under the stress applied by direct tension or compression, torsion, bending, or a combination of these actions.

The existing concrete structures undergo both mechanical loads and environmental impacts simultaneously. For example, the bridges and highways in the cold regions are suffering from the coupling effects of fatigue loading and environmental factors such as freeze/thaw (F-T) cycles, and chloride ions. The mechanical loads and environmental factors influenced each other, which accelerates the damage of concrete structures and shortens their lifespan. The stresses in concrete under externally imposed loads and environmental effects resulted in the growth, propagation, and joining of micro-cracks which lead to the failure of the concrete (Qiao et al., 2015).

2.2.3 Structure maintenance

The heavily used of concrete and mortar consequently cause high demand of maintenance and repairing work to reverse the deterioration, damage, defects in the structures, changes made on the building used, and to maintain the quality of the concrete structures to prolong their lifespan. In many cases, repairing and strengthening of the concrete structures must be carried out a few years after the

completion of the construction, or sometimes immediately after that. The dramatic growth in the repairing and strengthening of the concrete structure over the past 30 years have resulted in the need of many improvements in material, design practice, installation procedures, contracting processes, quality assurance or quality control procedures, and education. These improvements are needed to enhance the service life, to reduce the costs, and to minimise the conflicts (Emmons & Sordyl, 2006).

Civil infrastructures are necessarily needed to be maintained safely for the well-being of humankind. The ageing of the structures will increase the complexity of the operation and the maintenance process (Chang et al., 2003). Besides, the need to maintain the concrete structure is affected by deterioration and degradation factors of the concrete structure. Islam et al. (2014) stated that concrete degradation, steel corrosion, changes in boundary conditions, and weakening of the connection in structures over time are among the major concerns. If a damage remains unattended, the structural integrity and the service capability would deteriorate over time.

2.2.4 Structure deterioration and degradation

The durability of concrete is one of the most important properties because the concrete should essentially capable of withstanding the conditions for which it has been designed throughout the lifespan of a structure. Deterioration or lack of durability can be the result of external agents arising from the environment or by internal agents within the concrete (Neville & Brooks, 2002).

Structure deterioration is a phenomenon with negative impacts on the function (loss of strength), the unsafe conditions, and the aesthetic of the structure. The effects of concrete deterioration are corrosion of embedded metals, freeze-thaw, chemical attack, abrasion (erosion), fire (heat), overload, and surface defects. All of these effects may lead to the concrete cracking.

The concrete and the mortar structures, as well as other infrastructures, suffer deterioration usually due to water ingress during their lifespan. This is manifested by the corrosion of reinforcements followed with chloride permeability, acidic, and other chemical attacks and gaseous permeability. Moreover, the water permeation also affects the aesthetic appearance of an infrastructure (Muhammad et al., 2015).

2.3 Leakage in concrete structure

According to Al-Kadi et al. (2013), the term leakage is defined as a way of a fluid escaping to the outside containers, tanks, or pipes. Meanwhile, leakage in the context of the structure is a way, in a concrete or a mortar, which permits the fluid or gas to permeate across the structure. Leakage among residential buildings is more focused on fluid. The region with most leakage occurrence is probability at the bathroom. A bathroom is a wet place that is most frequently in contact with the fluid. During this frequent contact, a small amount of water will indirectly seep into the floor layer. The waterproofing coating applied to the concrete and the mortar layer helps in preventing this phenomenon. However, other problem may arise, where the fluid is trapped into the mortar layer. While the mortar layer is high in pressure, the trapped fluid is looking for a low-pressure space to escape. This phenomenon will cause other serious problems such as corrosion of the embedded metals, fungus at the structure surface, and deterioration of the concrete (Wan Nazri et al., 2017).

The leakage behaviour is considered undesirable due to the fluid system material and economic losses. Despite the material and economic losses, leakage can also cause huge disasters towards the environment if the raw material of the fluid is harmful or corrosive (Al-Kadi et al., 2013). For example, the leakage of a nuclear reactor will cause radiation. Radiation or nuclear disaster was due to the nuclear material that has been accidentally released in the area, resulted in the destruction of flora and fauna. At the same time, it will affect human health especially to the newborn babies suffering from various diseases such as genetic mutations, cancer, and premature growth.

Based on the previous findings, various solutions and innovations have been made to prevent and overcome this problem, such as applying waterproofing on the concrete layer and using epoxy injection in the concrete. However, this problem still occurred. A new technology or innovation is needed to enhance the existing product and technology. Preventing the water penetration into the deep layer of the concrete is not enough to prevent concrete slab leakage, since the behaviour of water keeps that searching on the occurrence of seepage and to flow through it (Xin et al., 1995).

2.3.1 Factor of leakage in a structure

The concrete is most commonly used in a various range of buildings including the residential and commercial building. Like the majority of other building materials, concrete constantly interacts with the surrounding conditions. The temperature, humidity, and other factors affect the moisture level in a concrete. Factors that are responsible for moisture problems are fast-track construction, structure surface cracking, improper moisture protection installed, and the omission of moisture protection.

2.3.1.1 Structure surface cracking

One of the main factors contributing to slab leakage phenomenon is the occurrence of a crack at the surface of the slab structure allowing the fluid to absorb into the slab layer and trapped in it (Wan Nazri et al., 2017). The fluid that is trapped in the slab layer will seep out through the slab crack fractures. Crack on the structure surface is usually caused by the vibration/movement of the structure, premature loading, excessive loading, and the deterioration of the structure surface (Jamali et al., 2013; Lee et al., 2015a; Siad et al., 2017).

2.3.1.2 Improper installation of moisture protection

All structures that are frequently in contact with water or may face the risk of moisture problems are usually installed with a moisture protection material, to prevent water from seeping into the building structure. Generally, a waterproof coating is used to prevent the seepage of water into the concrete or the mortar layer. The improper installation of the waterproof coating will cause leakage problem in a building due to water penetration into the structure. The waterproof coating should be applied carefully to the entire surface structure and needs to cover the entire surface influenced by the water. Structure surface that is not fully covered with the waterproof coating will then cause the penetration of liquid into the structure and resulted in the risk of floor leakage because the concrete and the mortar layer are porous materials (Muhammad et al., 2015).

Meanwhile, Muhammad et al., (2015) also listed another eight factors that contribute to the unfunctional or less effective of the waterproof layer which are:

i. Type of waterproof material used
ii. Mix material used
iii. Thickness of overlay
iv. Thickness of membrane
v. Surface Preparation
vi. Surface roughness
vii. Aggressive weather
viii. Aggressive temperature

2.3.2 Effects of leakage in structure

Water is an essential ingredient in concrete, but uncontrolled excessive moisture can create a cause of problems involving concrete. Moisture-related problems in the building structure are not a new issue nowadays. This issue is continuously occurred due to the lack of functional technology that is really capable in solving this problem.

2.3.2.1 Structure deterioration and degradation

Water and other liquid permeation into the structure can result in the deterioration and the degradation of the structure, as well as other aesthetic problems that shorten the structure lifespan. The permeated fluid in the slab will cause many problems to the building in the future, such as corrosion of the steel reinforcement, fungus attack on the wall surface, formation of stalactites from the concrete slab, and disturbing of the electrical wiring system. Penetration of water into the concrete layer existed in the form of moisture, can affect the durability of the building structure, such as the wall and the floor. High levels of moisture resulted in the corrosion of reinforcement bar inside the concrete and promoting the growth of microorganisms due to the migration of moisture through the wall (Lu, 2002; Piaia et al., 2013). This statement was supported by Song et al. (2009) claiming that concrete leakage through the crack, especially for hydraulic concrete, is a key factor contributing to concrete

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